“Double Master in Energy Engineering and in Renewable Energy Science and Technology”

Universitat Politècnica de Catalunya/École Polytechnique - Université Paris-Saclay.

INTERNSHIP REPORT:

Solar Power Engineer at Power Providers

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0. Abstract

This document will try to compile all the work done by Mario Madalena Rodríguez during his internship at Power Providers in Tanzania. The report will firstly, present the energy situation in the developing countries in general and in Tanzania in particular. Power Providers is a company based on Arusha (Tanzania) devoted to provide renewable energy solutions throughout East Africa. The company will be introduced and their main areas of work will be presented to better understand the outreach of this company. Finally the tasks the intern has been involved will be described and explained and some projects will be given as example of these tasks.

1. Introduction

Our ancestors became human beings thousands years ago with the mastery of fire and other energy forms. Thus, the energy is not one more right among the human rights but is the key for the economic and social development of the human race. As well as we all have the right to education and to health, we also have the right to have access to the electric energy in order to satisfy every fundamental right.

Looking back:

With the advance of the old empires the slaves became the main energy source, which satisfied the main needs and commodities of the dominant classes in Egypt, Rome and Greece. From the discovery of the steam engine in 1776, the humankind become more productive and able to take advantage of all the fossil resources, not exploded so far. Coal was the first fossil fuel to power the steamboat, the rail and the first factories that brought forth the industrial revolution in the XIX century. After that, the oil age started, when the fossil fuels consumptions grew dramatically during the XX century accordingly with the emergence of the consumer society.

Electric Energy. A human right.

In most of western countries the access to electrical energy is something that we take for granted, when we flip the switch we expect the room to get enlighten, when we are cold, we expect to have electricity to heat up our households, when we are hungry, we expect to be able to turn on the stoves to cook a satisfying meal. However, this is not the reality in most of the developing countries.

Approximately one of every five people in the world has no access to electricity and nearly 1.3 billion people in Sub-Saharan Africa. (1)

We call energy is the capacity of a physical system to do work. Work it's done, physically speaking when we move an object using a force. Energy has plenty of forms, from mechanical (when a body or fluid falls or moves) to thermal or electrical. Electrical energy is an energy vector, which we used to be transformed into a useful energy or work. Electricity can get transform through the electrical appliances, engines, etc. into light, sound, mechanical energy, heat, etc. Thanks to electrical energy we can preserve, cook and cleanly eat our food which is in relation with health, we can enlighten our rooms, have access to the media and have access to informatics and internet which is directly related with the quality of the education. Thanks to electricity we can make our tasks easier, more efficient and productive. Living without electricity makes daily tasks that we take for granted impossible or extremely difficult. Without generated light, activities like studying, shopping and farming must be undertaken during the limited hours of sunlight. In essence, electrical energy is an indispensable basic need and it is part of the economic and social human rights. It’s our responsibility to ensure the access to electricity to every person in the world. Giving access to energy could transform people lives. Electricity reduces poverty and mortality, improves health, increases productivity and improves standards of living.

2. Tanzania Energy Situation

Electricity was first used in Tanzania in 1908 (2), when a railway company installed the first power generator in what was then Germany's East African colony in Dar es Salaam. In the following four decades, colonial administrators, utility company officials, and (after 1931) managers of the privatized Tanganyika power utility limited their efforts to meeting the demand of the small European communities in the city and of the plantation agriculture, instead of developing new markets among Africans (Straeten, 2015). Thus, by the 1950s, when universal access to electricity was almost achieved in Europe and the United States, electricity was only available for a few hundred customers in the capital and some towns of Tanganyika, then under British mandate.

After its independence in 1962, Tanganyika united with neighbouring Zanzibar to form the United Republic of Tanzania in 1964. In that same year, the government of Tanzania acquired shares in the private Tanganyika Electricity Supply Company and Dar es Salaam Electricity Supply Company, which became fully nationalized and merged to form TANESCO in 1975 (Ghanadan, 2009). At the beginning of this period, in 1960, total installed capacity in the country had been below 50 MW. Then, focusing on large-scale generation and the establishment of a centralized power grid, with credit from the World Bank and technical assistance from SIDA, TANESCO added 380 MW of hydropower to the national grid by 1990. The overall electrification rate was 6.8 per cent in 1990 (IEA), and though access in urban areas deepened, the lack of any coordinated rural energy planning (Straeten, 2015) meant that less than 1 per cent of the rural population had access to electricity in 1990. (2)

In 1992, catalyzed by macro-reform priorities, national energy policy, drought-induced electricity crises, and changes in World Bank's lending policy, the government of Tanzania initiated reforms in the power sector, which originally aimed to restructure and unbundle the power sector for eventual privatization (Diu, 2011). TANESCO was performing adequately throughout the 1970s and 1980s, but the performance of the utility gradually declined toward the end of the 1980s. It was unable to cover its operation and maintenance costs and debt service repayment from its collected revenue: the average tariff was below costs levels in the early 1990s due to reluctance to increase tariffs during prescribed currency devaluation. Furthermore, TANESCO experienced difficulties in enforcing payments for services and arrears. The weak financial position of the company led to insufficient investment in generation capacity and network reinforcement, power outages and distribution losses increased accordingly, lasting until the end of the 1990s despite tariff increases in the middle of that decade.

In 2002, TANESCO was placed under a two-year management contract with the South African company NET Group Solutions, in pursuit of a financial turnaround in view of privatization. NET Group Solutions implemented measures to increase revenues, mainly through enforcing collections and arrears payments and applying disconnection in the case of non-payment, even to high-profile customers such as the police or the national post office. Between 2002 and 2004, TANESCO revenue collection doubled. The management contract was extended for two years in 2004, during which time the focus was to include improvement in electrification and system reliability targets. By the end of the contract, technical turnaround was limited, with poor hydrological conditions, costly contracts with IPPs, and insufficient tariff rates15 cited as obstacles. Electrification rates stagnated between 1990 and 2008. (3)

Currently, the main drivers of electrification in Tanzania are political priorities and development policies, as demonstrated by the creation of the REA in 2005 and the setting of aggressive electrification targets. The target-driven National Electrification Program is financed by the REA-managed Rural Energy Fund, which is funded by donor contributions, levies on electricity, and levies on liquid fuel import and purchase. At the end of 2013, TANESCO had about 1.3 million connected customers. Beginning in 2014, a densification program is proposed to increase the number of customers from already electrified settlements by 1.8 million. A three-phase grid extension program, involving 5,526 settlements, is expected to further increase the total number of customers connected by 2022 to more than 5 million (Innovation Energie Developpement, 2014). A successful electrification programme requires timely and sufficient investment in generation capacity and in network infrastructure. While the private sector is expected to contribute to invest in generation capacity via the PPP and SPP frameworks which have been established recently, it is not expected to engage in grid extension, which is seen as economically unprofitable.

Tanzania population has been growing with an annual growth rate of 2.9% since 1967 reaching the 51 million people that nowadays live in Tanzania. Although in most of cities in Tanzania the grid is available in rural regions most of people don't have access to electricity. In February 2017 50.7% of the rural population in Tanzania didn't have electricity at home and 32.5% of the total population of Tanzania (Mainland) didn't have access to electricity. This means only 67.5% of the total population in Tanzania had access to electricity in February 2017. (4)

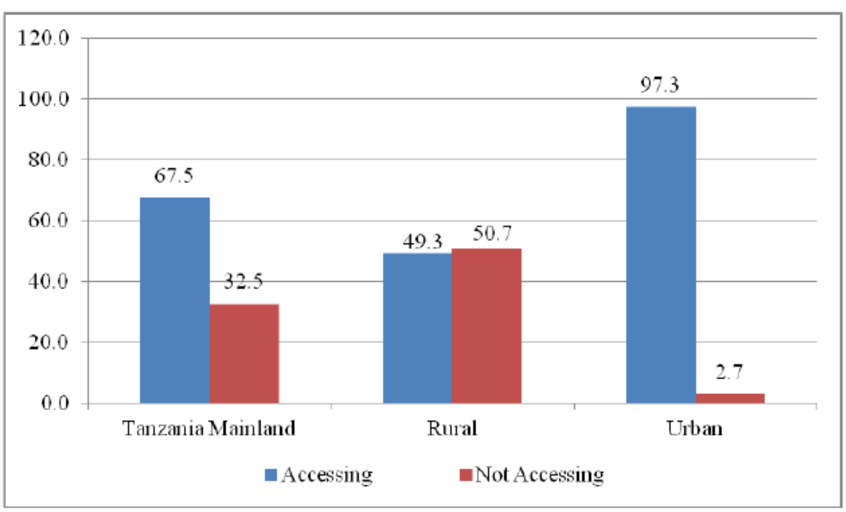

Figure. 1 Percentage distribution of population accessing and not accessing to grid electricity by place of residence. (4)

Since in most of rural regions there is no access to the grid because of logistic reasons and technical difficulties other sources of energy need to be found to provide the population with electricity. Solar is being the main alternative source of electricity in Tanzania:

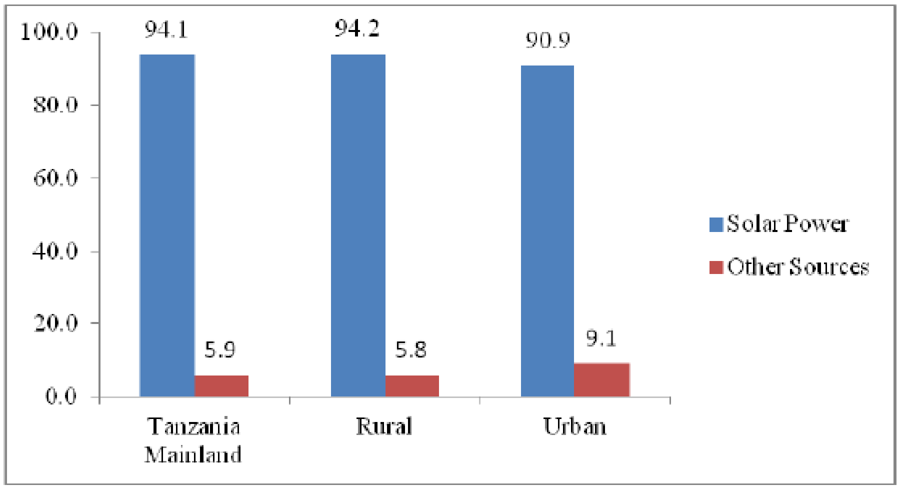

Figure. 2 Percentage Distribution on the type of alternative sources of electricity in Tanzania. (4)

Nowadays 94.1% of the alternative sources of electricity used in Tanzania is solar power, being 94.2% in rural areas as well as 90.9% in urban areas.

3. Power Providers Limited

Power Providers Limited is a company born in 2007 in Arusha, Tanzania, founded by a British to address a growing need for quality solar power systems in remote areas in East Africa (5). Power Providers has grown ever since based on the conviction that developing alternatives to fossil fuels is imperative for sustainable human development. Nowadays Power Providers headquarters is based in Arusha, providing renewable energy solutions to schools, hospitals, major tour operators, farms, hotels and industrial facilities as well as NGO's and conservation organizations

Due to the necessities and the potential of Tanzania, Power Providers has specialized in solar energy being focused in this 4 main fields:

Solar Power Systems

As an important percentage of the population has no access to electricity because the grid is not expanded enough, another energy solutions are needed to provide with electricity this part of the population. Due to the good location of Tanzania on the Earth, solar is the most logical choice to satisfy the electricity needs in a sustainable way. That's the main reasons Power Providers has specialized in solar power systems. Solar power systems can be feasible not only for off grid systems but also to grid-tied systems, when the target is to cut down the energy bill or to provide power security during the regular blackouts suffered.

These systems usually include a solar array and all the devices needed to adjust the power generated and most of them are combined with an energy storage, a battery bank. A generator can be assigned for backup purposes in poor sun months and for increased power security. Usually the systems designed by Power Providers are constituted by the following parts:

- Solar Array: The number of solar modules will be determined depending on the energy needs. Solar modules are meant to transform the energy that comes from the sun as irradiation in electricity.

- Charge Controller: This device is meant to control where the energy goes. When a battery bank is existing the charge controller will send the energy to the loads or to the battery bank depending on the established settings.

- Inverter: This device is needed to transform the continuous current generated by the modules to the alternative current needed by most of the loads. In other words, the inverter rise the voltage up to 220-230V, so the commercial devices can be used with this generated power.

- Battery Bank: Batteries are meant to store the excess of energy for later usage when the sun is not available. Off-grid systems need to have a battery bank, otherwise, electricity will be only available during day and there would be no other energy source during night. The battery bank is normally the trickiest and most problematic part of the systems, since the batteries are really expensive (especially in Tanzania) and really easy to damage if a good maintenance and operation is not performed.

- Generator: In some cases, the solar array cannot be as big as desired and it cannot cover the energy demand, either because of space reasons or because of budget reasons. In this cases, when the grid is not available, an extra energy source is needed and a generator must be installed. Generators can normally be avoided by increasing the solar array, however sometimes is more practical to use a generator, although it has some important drawbacks like the use of fuel and the noises produced.

- Balance of System: The balance of system is the set of all the devices used for protections, to connect the devices between them and to assure the proper operation of the system. Power Providers is applying all the regulations in the National Electric Code of America, being one of the few companies that is installing safe and reliable systems. All the systems provided by the company will have voltage stabilizers if the system is connected to the grid, the proper breakers between all the devices, surge protectors, change over switches, lightening protection devices, etc.

Figure. 3 Solar Power System installed by Power Providers in Serengeti National Park.

Solar Water Heaters

Power Providers is really committed with electricity generated by using renewable energy, but also is betting in thermal energy generated by using the sun. Especially in remote areas, the use of regular water heaters can be difficult, since the fuel needs to be transported or because the energy bill is too expensive. Solar water heaters can provide hot water for normal use using the energy from the sun.

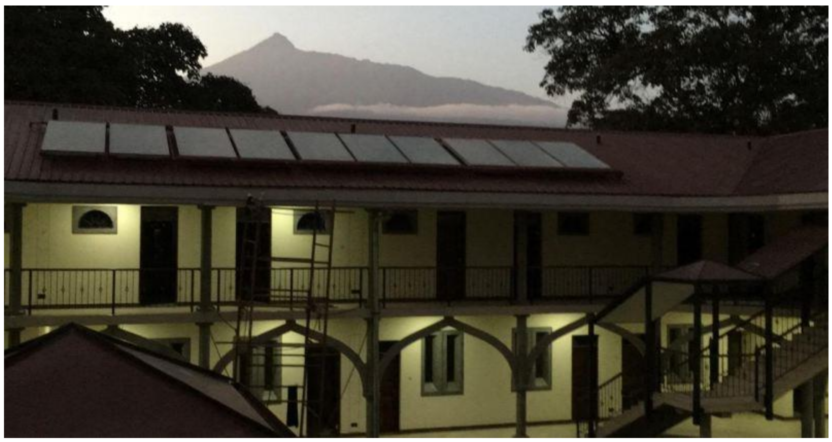

Figure. 4 Solar Water Heaters installed on top of a roof in a hotel located in Arusha.

Solar Water Pumping

Getting water to the right place is both energy intensive and costly. In East Africa in general, and Tanzania in particular, providing energy to rural areas for water pumping purposes can be logistically difficult and expensive. As such, solar pumping systems are rapidly developing to replace old-fashioned, labor or fuel intensive pump systems. Power Providers installs solar water pumping systems that takes care of the entire pumping process: from pumping water out of the ground to point of end use (drinking, domestic or irrigation).

The advantages of using solar as a power source to pump water are plenty. It needs relatively little maintenance and even in remote locations it can be assured that the system will operate properly and keep doing its job. Solar water pump systems are rapidly replacing human, grid or diesel, powered pumps and are frequently used to provide water to villages, the hospitality industry and the agricultural sector. It is financially viable as maintenance and fuel costs will decrease, while simultaneously using clean and reliable renewable energy harnessed from the sun.

Main components of a solar water pumping system:

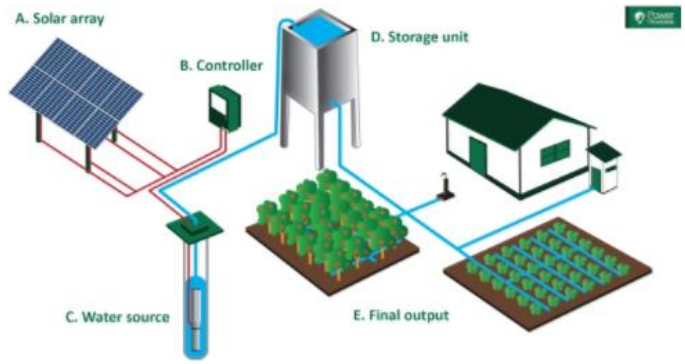

Figure. 5 Components of a solar water pumping system.

- Solar Array: Capture the irradiation from the sun and turn it into electricity.
- Controller: Adjust the electricity going towards the pump, turns on and of the pump.
- Pump: Special DC pumps used only with solar.
- Storage Unit: A water tank is needed to store all the water pumped during day.

Figure. 6 Solar Water Pumping System installed by Power Providers.

Back-up Systems

With the frequent outages due to the grid in Tanzania or the no connection to the grid at all, backup power systems are essential to assure a continuous source of power. Battery banks can either store energy from a solar array, from the grid or can be combined with a generator. Solar power systems normally include a battery bank, however, a stand-alone battery bank connected to the grid can also be possible to provide power security during the power outages of the grid.

Dependent on the use of the battery system it's combined with the relevant inverters and charge controllers or, sometimes, directly connected to a DC-load. Power Providers is specialized in larger systems with power requirements higher than 3kW and storage capacity of 1000Ah at 12V.

- **Other services:** Even though the design and installation of solar power systems has become the core business of Power Providers, the company has acquired the experience to be able to provide other services as follow:

    - Wind Power Systems: Wind turbines are an excellent and renewable source of power, as long as there is wind available to drive them. Power Providers use available wind ate to evaluate the appropriateness of a proposed site and, where data is not available, the company can supply and install data loggers to collect accurate and reliable site specific data. With the collected date, the potential of the installation of a wind turbine or wind farm can be evaluated to make a final decision with regards to if to install a wind turbine is feasible or not and which kind of wind turbine should be installed.

Figure. 7 Wind turbine installed in Arusha.

    - Solar/DC Cooling and Fridges: Power Providers is selling low energy consumption fridges and freezers that use highly efficient DC brushless motors to drive the compressors that are the heart of the cooling cycle. These efficient compressors combined with the high levels of quality insulation used to insulate the fridge or freezer cabinet result in a very low consumption profile when compared to most domestic fridges and freezers using AC power.

    - LED Lights: LED Lights are currently the most efficient method of lighting. The investment require to replace alternative lights with LED is often earned back within one or two years, since the energy savings are considerable and the lifespan of LED lights can be ten to twenty years.

The team

Power providers consist of a balanced collection of professionals specialized in the different fields needed to run a solar company:

Figure. 8 Power Provider's team.

- Manager Director: Clive Jones is not only one of the cofounders of the company but also the manager director. His commitment is about supervise the company is doing well and everybody is working properly. The manager director is involved in all the areas and is the maximum responsible of the company.

- Business developer: It's in charge of developing the company, hire people, fire people, look for new business opportunities, set the rules of the company, etc.

- Marketing department: Although marketing is not very developed in East Africa, this team is trying to advertise and make known the company to increase their sells and business opportunities.

- Technicians: This department almost represents 50% of the company. Technicians are meant to install and to provide maintenance after installation of all the systems the company is dealing with. Since most of people in Tanzania, ignore solar and electricity in general, technicians have and really crucial and important role that can make a big difference.

- Financial department: This department is managing the accounts and financial situation of the company. They deal with the banks and other companies in order to keep the company financially stable.

- Store department: Since most of the products are imported from Europe and the US, a store is needed to be able to keep a big set of products before they get sold. The stores team need to control what goes in and out of the stores as well as to make sure that stock is always available.

- Engineers: This department is meant to design all the systems, to advise the clients and to provide technical support both to the technicians and the clients.

4. Role in the company

As Solar Power Engineer, I've been involved in different tasks during my 6 months of internship. These have been the main tasks developed during this period:

a. Design of solar power systems based on load analysis previously performed. Use of solar power systems designing software.

The design and sizing of solar power systems to provide energy solutions has been the main task performed during the 6 months of internship. From the very beginning to the end I've been involved in most of the designs carried out by Power Providers, being present in all the stages of this process:

1. Site Survey:

Before starting the sizing some data is needed. A site survey is performed where the solar power systems needs to be installed. The following data is gathered:

- Grid Availability
- Existence of Generator
- Distances between the array area and the between the different devices needed
- Location of the installation, possible shadows
- Clients Comments
- Load Analysis

Power Providers

Survey For:
Client Name:
Lead Technician:

Survey Report for Solar / Backup / Generator

Date of Survey Place of Survey

Current Situation

Tanesco Is there currently a Tanesco connection? ☐ No Tanesco ☐ One-phase ☐ Three-phase

- If so, what is the location of the connection
- If so, what type of meter is used?

In case there is a Tanesco Connection, please ask for recent Tanesco billing. If availble, ask to send via e-mail OR take pictures of the bills. No ☐ Yes ☐

Generator Is there a back-up generator? ☐ No ☐ Yes

- If so, what is the location of the generator?
- If so, what is the brand/model of the generator?

In case there is a generator, please ask for recent Diesel billing and a logbook. If availble, ask to send via e-mail OR take pictures of the bills/logbook. No ☐ Yes ☐

Water Heating: Is there any water heated, if so, how?

Water Pumping: Is there any water pumping, if so, how?

Connection: Is there an internet connection? ☐ No Internet ☐ Wifi ☐ Ethernet

Is there celluar reception? ☐ Airtel ☐ Vodacom ☐ .... ☐ ....

Location / Distance

	Location	Distance to (in meters)
Solar Modules		Charge Controller
Charge Controller		Batteries
Batteries		Inverter
Inverters		Distribution Board
Generator		Distribution Board

Please ensure to take pictures of:

Tanesco line	☐	Generator	☐	Main switchboard	☐
Tanesco meter	☐	Diesel billing	☐	All buildings	☐
Tanesco billing	☐	Generator logbook	☐	All appliances	☐
Future location of solar modules			☐	Internet connection	☐
Future location of batteries			☐	Water pump	☐
Future location of charge controller and inverter			☐	Water heaters	☐

Figure. 9 Power Provider's site survey template.

2. Load Analysis

The load analysis is always the core of every solar power system sizing. When a load analysis is performed an accurate examination of all the rooms of the buildings is needed. The technician/engineer have to carefully go through all the rooms one by one writing down all the consumptions of the different rooms, taking into account the power of every device as well as their estimate usage. Once the data is gathered it needs to be analyzed either with software of with a spreadsheet. When the load analysis has been performed the following data will be used for the calculations:

- Average Daily Energy Consumption (kWh/day): This is the average consumption of electricity in a daily basis.
- Peak Power (W): This is the total power that would be required if all the appliances are working at the same time.
- Priority Peak Power (W): This is similar to peak power, but giving priority to some appliances and ignoring the rest. This is the one that would be used to calculate the nominal power of the inverter.

POWER PROVIDERS COMPANY LIMITED
LOAD ANALYSIS

Project:	Solar Power System
Client Name:	Pallotine Sisters
Site Location:	Tengeru

Electrical Loads	Qty	Volts	AC=1 DC=0	Priority=1 Not=0	Run Watts	Total Watts	Hours /Day	Days /Wk	Phantom-Load Watts	Surge Watts	Ave. WH /Day	Percent of Total
Sisters Bedrooms+Toilets												
Lightbulbs	10	230	1	1	12	120	3.00	7			360.0	2.7%
Socket outlets	4	230	1	1	15	60	1.00	7			60.0	0.5%
Novices Bedrooms+Toilets												
Lightbulbs	20	230	1	1	12	240	3.00	7			720.0	5.5%
Sitting-room (Sisters+Novices)												
Lightbulbs	4	230	1	1	12	48	2.00	7			96.0	0.7%
Radio	1	230	1	1	15	15	2.00	7			30.0	0.2%
TV	2	230	1	1	90	180	2.00	7			360.0	2.7%
Staircase/Hallway												
Lightbulbs	6	230	1	1	12	72	3.00	7			216.0	1.6%
Administration												
Bedroom lightbulbs	12	230	1	1	12	144	3.00	7			432.0	3.3%
Socket outlets	6	230	1	1	15	90	1.00	7			90.0	0.7%
Office												
Lightbulbs	2	230	1	0	12	24	2.00	5			34.3	0.3%
Desktop computer	2	230	1	1	100	200	6.00	5			857.1	6.5%
Printer	1	230	1	0	500	500	0.17	2			24.3	0.2%
Photocopy machine	1	230	1	0	700	700	0.17	2			34.0	0.3%
Scanner	1	230	1	0	18	18	0.25	5			3.2	0.0%
Wifi-router	1	230	1	1	25	25	24.00	7			600.0	4.6%
Library												
Lightbulbs	4	230	1	1	12	48	2.00	7			96.0	0.7%
Classroom												
Lightbulbs	2	230	1	1	12	24	2.00	7			48.0	0.4%
Sewing room												

POWER PROVIDERS COMPANY LIMITED
LOAD ANALYSIS

Electrical Loads	Qty	Volts	AC=1 DC=0	Priority=1 Not=0	Run Watts	Total Watts	Hours /Day	Days /Wk	Phantom-Load Watts	Surge Watts	Ave. WH /Day	Percent of Total
Kettle	1	230	1	1	1850	1850	0.25	7			462.5	3.5%
Garden Lights	2	230	1	1	25	50	8.00	7			400.0	3.0%
Security lights	12	230	1	1	12	144	8.00	7			1152.0	8.8%
Spot light	1	230	1	1	30	30	8.00	7			240.0	1.8%
Pump	1	230	1	1	450	450	0.00	7		1600	0.0	0.0%

Total Daily Average Watt-hrs	13143.0
Largest AC Appliance Wattage	707
Inverter Priority Wattage	10470
Largest AC Appliance Surge Wattage	3300
Total AC Wattage (Inverter Power Demand)	12327.0
Total Daily Average AC Watt-hrs	13143.0
Estimated Monthly Consumption (kWh)	394.3

Figure. 10 Power Providers load analysis example.

3. Solar Power System Sizing

Once we got all the key data from the load analysis the process can continue and the sizing can get started. Thanks to the software developed, the sizing becomes pretty simple and straight-forward, however there are some values that need to be implemented:

- Days of autonomy: The days of autonomy is the period while the appliances specified in the load analysis could be running only powered by the batteries. To select the number of days of autonomy we have to look at the historical data of the location. We can find the maximum equivalent days with no sun in a given period of time that will give an idea of how many days of autonomy is needed. The fact of having a generator as a backup system will also strongly affect this decision.

- Efficiencies: Big part of the power generated by the modules get lost in the different devices and in the wires. In order to take this losses into account, efficiencies due to devices general efficiency, temperature, degradation, need to be considered.

- Deep of Discharge (of batteries): The batteries used for solar power systems are special batteries that are constantly being charged and discharged. In order to along the lifespan of solar batteries, they should never be discharged more than 50% of their nominal capacity.

- Peak Sun Hours: This depends exclusively on the location of the installation. This data can be looked up on NASA database, implementing the coordinates of the location and looking at the irradiation data of that location (kWh/m2/day in a horizontal surface with a normal irradiation of 1000W/m2).

- System Voltage: The system voltage will depend not only on the size of the system but also on the availability of the devices. Normally small systems tend to be 12V or 24V, since the devices needed match with this voltage. However when the system is bigger, a 48V systems should be used.

System

System Voltage	24,0
Peak Sun Hours	4,8
Days of Autonomy	3,0
Discharge Limit	0,5
System Type	Hybrid
Extra Loads %	0,00%

Table. 1 Settings to implement on Power Provider's sizing software.

4. Quotation

After the system is design and all the specifications are made, the clients need to receive an offer with all the specifications and listing of the components of the systems and also with the breakdown of the costs. The quotations are made by the engineers, since they know what components are needed and what the additional costs could be.

Controller Type	MPPT	
Include	**Cost Outline:**	
YES	Solar Modules (3180Watts)	$3,180.0
YES	Charge Controller VE Blue Solar MMPT 150/70 x	$820.0
YES	Battery bank 800Ah 48V	$6,400.0
YES	Inverter Victron Energy I/C 3000VA 48V Multi	$2,050.0
YES	Balance of System Estimate	$4,822.3
YES	Installation	$1,557.6
YES	Transport	$1,557.6
	TOTAL CLIENT ESTIMATE	**$20,387.5**

Table. 2 Power Provider´s quotation example.

5. Installation

Technicians are in charge of performing the installation of the solar power systems, however, the supervision of an engineer is sometimes needed in order to improve the understanding of the technicians, make sure that the system is installed properly or to make sure that some special requirements or client suggestions are also achieved.

b. Field work to get understanding for systems upgrading or new systems implementation, load analysis performance, site surveys, systems service and maintenance, etc.

From the beginning I was very involved in the field work to get to know how the company works and to quickly understand all the procedures and all the steps needed to succeed in a solar power installation.

During my field work I was involved in different tasks being the main ones as follows:

- Site Survey: Going to potential clients to have a look at the possible location for the solar power system, complete a load analysis, check the availability of the grid, check the potential options for solar power systems…
- Technical Maintenance / Service: Going to installations done by Power Providers to do the regular checking or for troubleshooting.

- Installations: Going with the technicians to install a designed solar power systems, working and supervising the technicians, to ensure the solar power system is installed properly and following all the requirements.

c. Provide one of the Power Provider's trainees with assistance in designs and fieldwork.

Although Tanzania possess universities and relatively good technical schools, local engineers are not as prepared as western engineers just after university, especially in specific areas due to the university systems is not as wide as in developed countries. Solar technology is a really specific subject that is not common in Tanzania and difficult to be seen in a university.

For Power Providers this means that, even if they hire an electrical engineer an additional training is needed to become familiar with the solar technology and all the related knowledge needed to become a solar power engineer.

One of my main tasks was to train one of the interns of Power Providers in order to teach here all the theory of solar as well as all the processes to design a solar power system.

d. Writing reports analyzing real data obtained from data loggers for potential future installations.

For potential big systems, to perform a load analysis was not feasible, both due to the size of the system and to the lack of knowledge about the nominal power of some appliances as well as to the lack of information about running times. In these cases, data loggers, needed to be installed to record the instantaneous consumption during a given period of time, so that, the consumption data could be analyzed.

After gathering all the data after a representative period of time, the data loggers output a set of data with the instant power per second or minute. The target of analyzing that data is to obtain the daily and hourly consumption as well as the maximum power needed.

Once the data is analyzed a report needs to be done in order to wrap up all the information and to put it in a document to ease and to speed up understanding for both Power Providers and the client. Normally the data analyzed is already presented with the possible solar power options that could meet the requirements for the consumptions given.

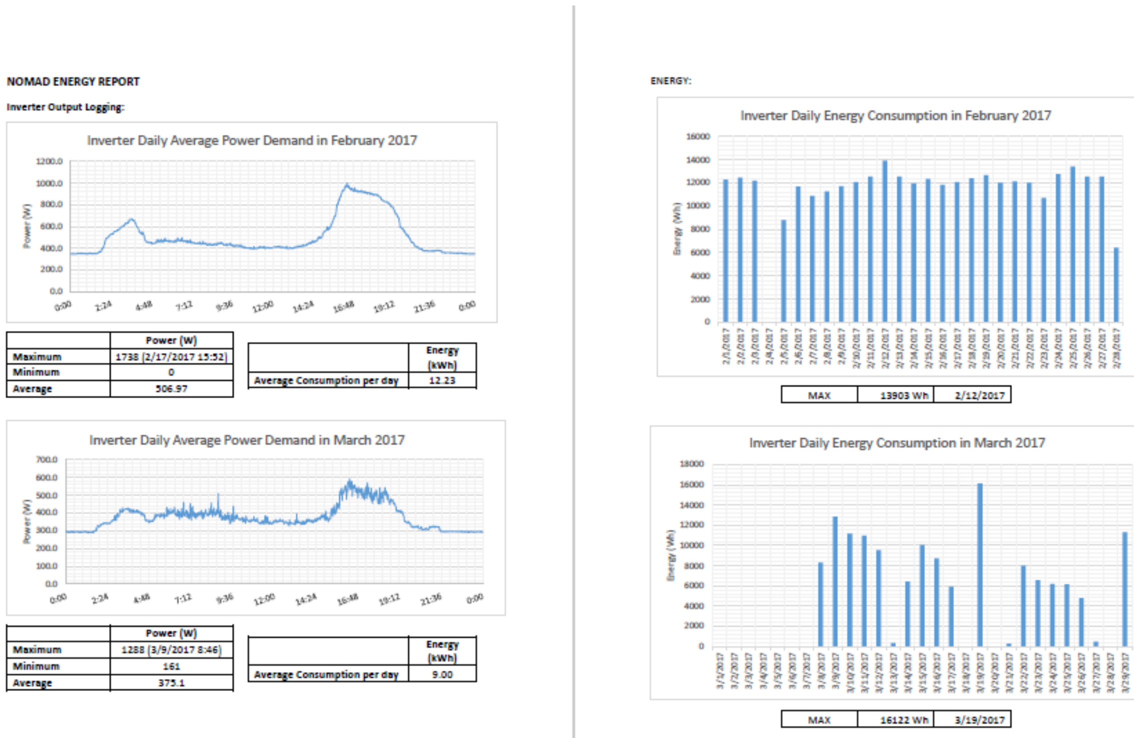

Figure. 11 An example of a report made out of data provided by data loggers.

e. Creation of standard packages for back-up system and off-grid solar power systems.

Despite Power Providers tailor make all the solar power systems and back-up systems, for the current solar power market, to have some standard packages to give an idea of the price depending on the size of the system is a must.

Although it seems to be a marketing task, to design the packages properly and to price them is an engineering task and specific technical knowledge is needed.

Pricelist Power Providers - Back-up Systems												
Victron Energy Inverter Chargers - Nominal Output												
Capacity (kWh)	Number of Bat.	Batt. in Series	Battery	System Voltage	800	1.200	1.600	2.000	3.000	5.000	8.000	10.000
1,32	1	1	Surrette AE-220	12V	$2.689	$3.045	$3.368	$3.588				
2,64	2	2	Surrette AE-220	12V	$3.097	$3.453	$3.776	$3.996				
2,64	2	1	Surrette AE-220	24V	$3.063	$3.369	$3.585	$3.946	$4.584			
3,96	3	3	Surrette AE-220	12V	$3.505	$3.861	$4.184	$4.812				
5,28	4	4	Surrette AE-220	12V	$3.913	$4.269	$4.592	$4.812				
5,28	4	2	Surrette AE-220	24V	$3.879	$4.185	$4.401	$4.762	$5.400			
7,92	6	3	Surrette AE-220	24V	$4.695	$5.001	$5.217	$5.578	$6.216			
10,56	8	4	Surrette AE-220	24V	$5.511	$5.817	$6.033	$6.394	$7.032			
10,272	8	2	Surrette S-550	24V	$6.327	$6.633	$6.849	$7.210	$7.848			
10,272	8	1	Surrette S-550	48V					$7.730	$9.250	$11.455	$12.155
15,408	12	3	Surrette S-550	24V	$8.359	$8.665	$8.881	$9.242	$9.880			
20,544	16	4	Surrette S-550	24V	$10.391	$10.697	$10.913	$11.274	$11.912			
20,544	16	2	Surrette S-550	48V					$11.794	$13.314	$15.519	$16.219
30,816	24	3	Surrette S-550	48V					$15.858	$17.378	$19.583	$20.283
41,088	32	4	Surrette S-550	48V					$19.922	$21.442	$23.647	$24.347
42,816	24	2	BAE PVS 2280	24V	$21.719	$22.025	$22.241	$22.602	$23.240			
85,632	48	2	BAE PVS 2280	48V					$42.578	$44.098	$46.303	$47.003
171,264	96	4	BAE PVS 2280	48V					$81.362	$82.882	$85.087	$85.787

Table. 3 Pricing for the different combinations of inverters and battery banks.

USD/Wh in Batteries- Back-up Systems												
Victron Energy Inverter Chargers - Nominal Output												
Capacity (kWh)	Number of Bat.	Batt. in Series	Surrette	System Voltage	800	1.200	1.600	2.000	3.000	5.000	8.000	10.000
1,32	1	1	Surrette AE-220	12V	2,04	2,31	2,55	2,72				
2,64	2	2	Surrette AE-220	12V	1,17	1,31	1,43	1,51				
2,6	2	1	Surrette AE-220	24V	1,16	1,28	1,36	1,49	1,74			
3,96	3	3	Surrette AE-220	12V	0,89	0,97	1,06	1,22				
5,28	4	4	Surrette AE-220	12V	0,74	0,81	0,87	0,91				
5,28	4	2	Surrette AE-220	24V	0,73	0,79	0,83	0,90	1,02			
7,92	6	3	Surrette AE-220	24V	0,59	0,63	0,66	0,70	0,78			
10,56	8	4	Surrette AE-220	24V	0,52	0,55	0,57	0,61	0,67			
10,272	8	2	Surrette S-550	24V	0,62	0,65	0,67	0,70	0,76			
10,272	8	1	Surrette S-550	48V					0,75	0,90	1,12	1,18
15,408	12	3	Surrette S-550	24V	0,54	0,56	0,58	0,60	0,64			
20,544	16	4	Surrette S-550	24V	0,51	0,52	0,53	0,55	0,58			
20,544	16	2	Surrette S-550	48V					0,57	0,65	0,76	0,79
30,816	24	3	Surrette S-550	48V					0,51	0,56	0,64	0,66
41,088	32	4	Surrette S-550	48V					0,48	0,52	0,58	0,59
42,816	24	2	BAE PVS 2280	24V	0,51	0,51	0,52	0,53	0,54			
85,632	48	2	BAE PVS 2280	48V					0,50	0,51	0,54	0,55
171,264	96	4	BAE PVS 2280	48V					0,48	0,48	0,50	0,50

Table. 4 Ratio USD/Wh of the different combinations.

f. Further development of the Power Providers solar power systems design software.

Since Power Providers was founded, its sales have been growing over the years, and thus the designs too. In order to be able to design all the systems demanded in time a design software is a must.

Power Providers possess a solar power system´s design tool that gives the company the readiness needed to be able to design and provide quotations to the clients as soon as possible.

Since Power Providers had already its own software to design, my main task was to improve it and make it more client-friendly as well as more easy and simple.

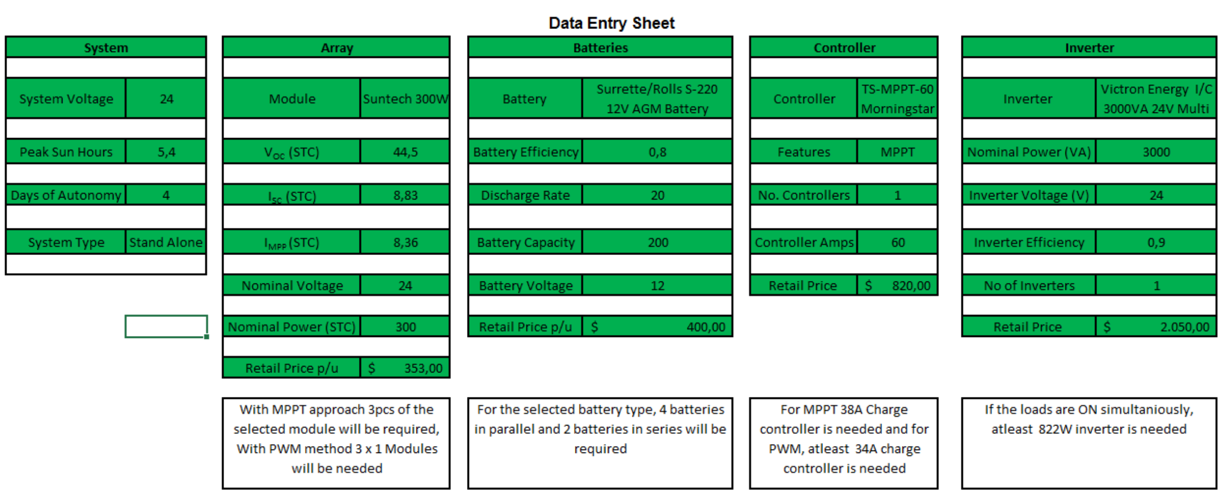

Figure. 12 Interface of the software created.

g. Analysis of business case of Solar Water Heating vs. Electrical Water Heating vs. Gas Water Heating in Tanzania.

Solar technology can be considered as emerging in Tanzania and is right now giving new alternatives not only for electricity production but also for thermal production. Right now most of the buildings equipped with hot water are using electrical water heaters or boilers burning LPG. Nowadays Solar Water Heaters are starting to be sold in Tanzania, being a really good option for remote and off-grid areas, where the transportation of the fuel becomes difficult and annoying. However an increase on the installation of the solar water heaters is not only happening in remote areas but also in big buildings in the city such hotels, schools, big apartments, etc. The fact that this technology is growing in Tanzania calls a need to compare it with the other current technologies to analyze which one is better in the different cases.

Since Power Providers has started to offer and install solar water heaters a business case has been proposed to compare solar water heaters with electrical water heaters and gas water heaters. Since there could be a massive amount of cases, only two representative cases have been analyzed:

- Case A: Normal family house with 4 members. Taking 4 showers a day of 25L of hot water at 50ºC.
- Case B: Hotel with around 25 rooms, being full, or a hotel with 50 rooms being half-full. Taking around 50 showers of 25l of hot water at 40ºC a day.

	Case A	Case B
	4 Showers of 25L of hot water a day at 40°C	50 Showers of 25L of hot water a day at 40°C
Initial temperature (°C)	25	25
Final Temperature (°C)	50	50
Volume a day (L)	100	1250
Cp (kJ/KgK)	4,18	4,18
Energy (kJ/day)	10450	130625
Energy (kWh/day)	2,9	36,3
Energy (kWh/year)	1059,5	13243,9

Price of Electricity ($/kWh)	0,16
LPG (MJ/kg)	46,1
LPG (kWh/kg)	12,8
Price of LPG ($/kg)	1,54
Price of LPG ($/kWh)	0,12
Price of Electricity LUKU ($/kWh)	0,16

Figure. 13 Input data for the water heating business case developed.

Considering real prices for boilers and solar water heaters, and real price of LPG and electricity in Tanzania. An economic analysis has been performed to analyse the cashflow over the years with a given interest rate.

With this business case template, when conditions change (interest rate, price of electricity, price of gas) its effects can easily be checked.

	CASE A		CASE B	
	CAPEX ($)	OPEX ($/year)	CAPEX ($)	OPEX ($/year)
Solar	$1.980,00	$0,00	$8.305,63	$ 194,66
Gas	$1.416,00	$ 144,79	$1.416,00	$ 1.809,91
Electric	$1.600,00	$ 172,87	$1.600,00	$ 2.160,85

Interest Rate	6%

CASH FLOWS

	CASE A										
	0	1	2	3	4	5	6	7	8	9	10
Solar	-$1.980,00	-$1.980,00	-$1.980,00	-$1.980,00	-$1.980,00	-$1.980,00	-$1.980,00	-$1.980,00	-$1.980,00	-$1.980,00	-$1.980,00
Gas	-$1.416,00	-$1.552,60	-$1.681,46	-$1.803,03	-$1.917,72	-$2.025,92	-$2.127,99	-$2.224,29	-$2.315,13	-$2.400,83	-$2.481,69
Electric	-$1.600,00	-$1.763,08	-$1.916,94	-$2.062,08	-$2.199,01	-$2.328,18	-$2.450,05	-$2.565,02	-$2.673,47	-$2.775,80	-$2.872,32

	CASE B										
	0	1	2	3	4	5	6	7	8	9	10
Solar	-$8.305,63	-$8.489,27	-$8.662,51	-$8.825,95	-$8.980,14	-$9.125,60	-$9.262,83	-$9.392,29	-$9.514,42	-$9.629,63	-$9.738,33
Gas	-$1.416,00	-$3.123,46	-$4.734,27	-$6.253,90	-$7.687,52	-$9.039,99	-$10.315,90	-$11.519,59	-$12.655,15	-$13.726,43	-$14.737,07
Electric	-$1.600,00	-$3.638,54	-$5.561,69	-$7.375,98	-$9.087,58	-$10.702,29	-$12.225,60	-$13.662,69	-$15.018,44	-$16.297,44	-$17.504,05

Figure. 14 Output of the water heating business case developed.

h. Modules vs Batteries

In most of developed countries solar power systems are becoming cheaper than years ago and over the years they are becoming more affordable and accessible to every pocket. However, the reality in Tanzania is pretty different. Since most of the devices needed for solar power systems, including panels, batteries, inverter and charge controllers, are being imported mainly from Europe, the US and China and the taxes have been increased considerably, these systems have become really expensive in East Africa, being really difficult for locals to afford them.

Since the high cost of the materials is becoming a big issue for the business, companies are looking for ways to cheapen the systems to increase their sells and to be able to provide solar power energy to more people.

Most of the solar power systems installed by Power Providers are equipped with batteries, which normally represents a big percentage of the total cost. For off-grid installations, batteries can represent from 30 to 50% of the total cost of the system. There are some reasons that can explain it:

- Government taxes: VAT has been recently increased in Tanzania and also the importation taxes.
- Transport: Batteries are heavy and difficult to transport and this increases the total costs considerably.
- Quality: Power Providers has been always using high quality materials for its solar power systems including for the batteries. To use high quality batteries means that they need to be acquired from top makes of developed countries such the US or Germany, being them really expensive.

- Designing Criteria: Power Providers is designing solar power systems that ensure power security even for the worst possible cases. When considering the days of autonomy of a given installation, Power Providers considers for the worst case in the last 60 years (NASA Data Base). Being so ambitious has some drawbacks: Since the designer is considering the worst case scenario it means that the system would be oversized during the rest of the time and the amount of batteries will be way higher than an average situation when the use of another back-up system can be considered.

Power Providers realized that this designing criteria was providing high power security but at the same time increasing the costs of its systems considerably, losing some clients in some cases.

Nowadays solar modules are becoming a lot cheaper even in Tanzania and we realized that even during the worst day of the year, the sun is irradiating some energy that can be used and depending on the amount of modules the total amount of energy captured can change. So we decided to make some calculations and to simulate different cases oversizing the solar array and undersizing the battery bank for a given number of days of autonomy in a given installation.

We considered a consumption of 10kWh a day located in Arusha, the normal efficiencies between array and batteries and between batteries and loads. We also considered that 2 no-sun equivalent days in 3 days. This means that in 3 consecutive days, 2 of them would be with no sun at all, or with other words, only 32% of the normal irradiation would be available during the 3 days of the simulation.

We created 8 different scenarios that represent 8 different systems, with different days of autonomy for the battery bank and different sizes of solar array. The A is the starting scenario, being the normal criteria used by Power Providers (solar array normally designed and 4 days of autonomy in batteries).

The different scenarios simulate how the system would behave during 3 consecutive days with only 32% of the sun and checking if the batteries will become empty (considering a deep of discharge of 50%) or how much energy will remain after that period.

With that we can compare the different prices of the different options trying to optimize to minimize the price for the same days of autonomy.

Daily Consumption (kWh)	10
Deep of Discharge (%)	50%
Charge Controller (%/kWp)	20%
MPPT efficiency Array to Battery (%)	60%
Efficiency Battery to Loads (%)	90%
No-Sun Days Equivalent in 3 days (days)	2
Non-sunny days (% of average day)	32%
Peak Sun Hours (h)	4,6
Days Considered	3
Minimum Days of Autonomy	2
Minimum Solar Array	1

Batteries	$/kWh
Surrette S-550 .6v 428AH	194,704
Available battery capacity	389,4081

Modules	$/kW
Suntech 265W	1000,00
With Charge Controller	1200,00

Scenario	A	B	C	D	E	F	G	Optimal*
Days of Autonomy	4	3	2	2	1	1	0,5	2
Solar Array (Oversized Times)	1	2	2,4	3	3	3,7	3,7	2,6
Estimated Cost ($)	$19.135	$19.833	$17.901	$20.532	$ 16.845	$19.915	$ 18.072	$ 18.904
Battery Charge after 3 non-sunny days (useful kWh)	19,70	19,40	13,28	19,10	9,10	15,89	10,89	15,5
Available Battery Capacity (kWh)	44,4	33,3	22,2	22,2	11,1	11,1	5,6	22,2
Solar Array Nominal Power (kW)	3,7	7,3	8,8	11,0	11,0	13,5	13,5	9,6

Capacity of the battery Ah at C20 (Ah)	428	428	428	428	428	428	428	428
Rated Discharge Time (h)	20	20	20	20	20	20	20	20
Actual Discharge Time (h)	40	30	20	20	10	10	5	20
Peukert's Exponent	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3
Actual Discharge Current (A)	12,6	15,7	21,4	21,4	36,5	36,5	62,2	21,4
Capacity at Required Discharge Rate (Ah)	502,2	470,0	428,0	428,0	364,7	364,7	310,8	428,0
$/kWh	331,8	354,6	389,4	389,4	457,0	457,0	536,2	389,4

Figure. 15 Study comparing the use of batteries with the use of more solar.

After this study, we realized that considering normally 4 days of autonomy was increasing the price significantly while the system was offering the same features or benefits that other cases which were cheaper.

This template is meant to change the way of designing of the company in the near future to decrease the costs of the installations while keep ensuring power security and reliability of the solar power systems.

5. Projects

During my internship in Power Providers I've been involved in lot of different projects that can be classified in:

- Solar Power Systems
- Back-Up Systems
- Technical Support

A. Solar Power Systems

Pallotine Systers Convent

Pallotine Systers Convent is a compound located in Tengeru, around 5km far from Arusha, where nuns live and stay when coming to Tanzania from all over the world. The convent is now being upgraded to be able to host more people as well as with better facilities and conditions.

Nowadays the energy bill of the whole property has been really expensive over the last years and power cuts are very frequent, producing lots of problems for the normal activity of the convent. Thus a solar power system could be considered to cut down the energy bill as well as provide power security during power outages. Although the convent possess a diesel generator, this is really noisy as well as expensive, so to avoid its use would be a plus.

Figure. 16 Pallotine Sister's Convent in Tengeru.

Although we got an estimation of the monthly consumption a load analysis was performed to estimate not only the daily consumption but also the main power consumptions as well as the distribution of the loads:

POWER PROVIDERS COMPANY LIMITED
LOAD ANALYSIS

Project:	Solar Power System
Client Name:	Pallotine Sisters
Site Location:	Tengeru

Electrical Loads	Qty	Volts	AC=1 DC=0	Priority=1 Not=0	Run Watts	Total Watts	Hours /Day	Days /Wk	Phantom-Load Watts	Surge Watts	Ave. WH /Day	Percent of Total
Sisters Bedrooms+Toilets												
Lightbulbs	10	230	1	1	12	120	3.00	7			360.0	2.7%
Socket outlets	4	230	1	1	15	60	1.00	7			60.0	0.5%
Novices Bedrooms+Toilets												
Lightbulbs	20	230	1	1	12	240	3.00	7			720.0	5.5%
Sitting-room (Sisters+Novices)												
Lightbulbs	4	230	1	1	12	48	2.00	7			96.0	0.7%
Radio	1	230	1	1	15	15	2.00	7			30.0	0.2%
TV	2	230	1	1	90	180	2.00	7			360.0	2.7%
Staircase/Hallway												
Lightbulbs	6	230	1	1	12	72	3.00	7			216.0	1.6%
Administration												
Bedroom lightbulbs	12	230	1	1	12	144	3.00	7			432.0	3.3%
Socket outlets	6	230	1	1	15	90	1.00	7			90.0	0.7%
Office												
Lightbulbs	2	230	1	0	12	24	2.00	5			34.3	0.3%
Desktop computer	2	230	1	1	100	200	6.00	5			857.1	6.5%
Printer	1	230	1	0	500	500	0.17	2			24.3	0.2%
Photocopy machine	1	230	1	0	700	700	0.17	2			34.0	0.3%
Scanner	1	230	1	0	18	18	0.25	5			3.2	0.0%
Wifi-router	1	230	1	1	25	25	24.00	7			600.0	4.6%
Library												
Lightbulbs	4	230	1	1	12	48	2.00	7			96.0	0.7%
Classroom												
Lightbulbs	2	230	1	1	12	24	2.00	7			48.0	0.4%
Sewing room												

Electrical Loads	Qty	Volts	AC=1 DC=0	Priority=1 Not=0	Run Watts	Total Watts	Hours /Day	Days /Wk	Phantom-Load Watts	Surge Watts	Ave. WH /Day	Percent of Total
Kettle	1	230	1	1	1850	1850	0.25	7			462.5	3.5%
Garden Lights	2	230	1	1	25	50	8.00	7			400.0	3.0%
Security lights	12	230	1	1	12	144	8.00	7			1152.0	8.8%
Spot light	1	230	1	1	30	30	8.00	7			240.0	1.8%
Pump	1	230	1	1	450	450	0.00	7		1600	0.0	0.0%

Total Daily Average Watt-hrs	13143.0
Largest AC Appliance Wattage	707
Inverter Priority Wattage	10470
Largest AC Appliance Surge Wattage	3300
Total AC Wattage (Inverter Power Demand)	12327.0
Total Daily Average AC Watt-hrs	13143.0
Estimated Monthly Consumption (kWh)	394.3

Figure. 17 Extarc of the Load Analisys of Pallotine Sisters Convent (6)

Once the consumption was understood as well as the loads, the focus needs to look at the current electrical distribution as well as the distribution of the loads on the three different phases:

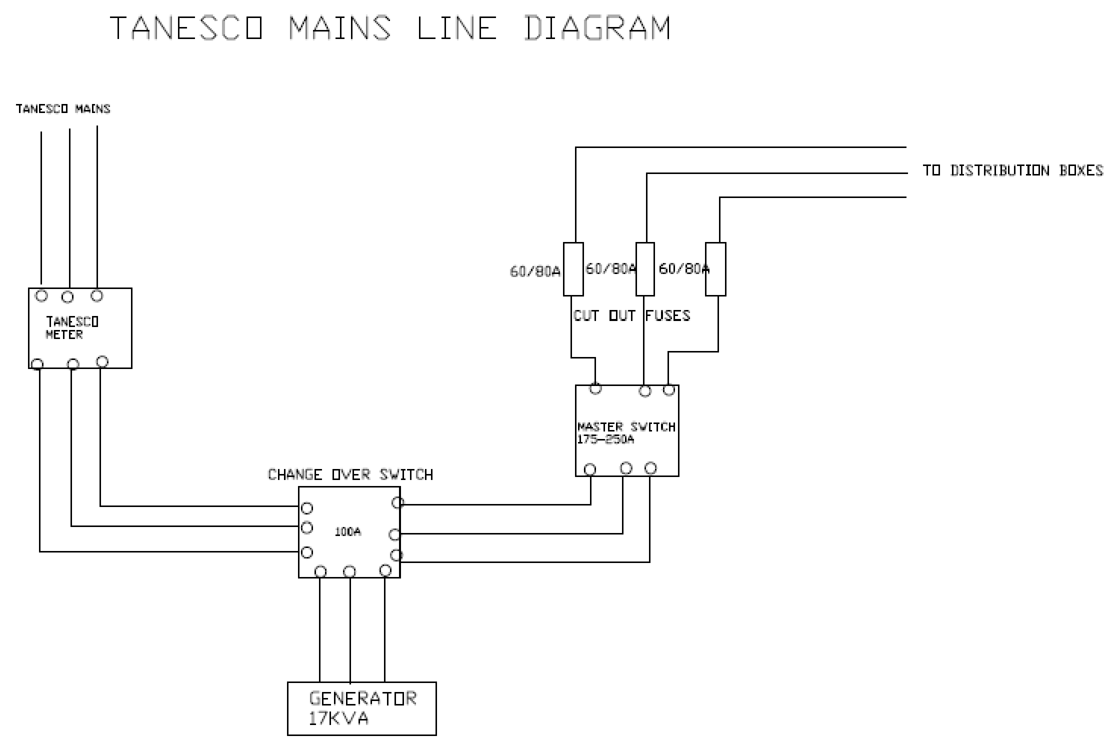

Figure. 18 Pallotine Sisters Convent Line Diagram of the Electric Distribution. (6)

Pallotine Sisters Phase Distribution

We tested the grid using voltage meters to know the voltage on each phase as well as the current going through each phase when all the loads of the property are connected:

Line to line voltage	Line to neutral Voltage	Phase current
L1-L2=364.2V	L1-N=206.5V	L1=9.9A
L2-L3=369.9V	L2-N=218.5V	L2=4.4A
L1-L3=362.5V	L3-N=211.5V	L3=6.2A

Table. 5 Measurements in the 3 phases of the Pallotine Sister's Convent

Phase Distribution

Phase 1: I= 9.9A, V=206.5V

- Feeds the administration block (upstairs & downstairs) the church and the dining room.
- Electrical loads: Lights, sockets, heating system and fridge.

Phase 2: I= 4.4A, V=218.5V

- Feeds Dormitories (upstairs + downstairs) and laundry room.
- Electrical loads: Lights, sockets, washing machine and irons.

Phase 3: I=6.2A, V=211.5V

- Feeds Sisters dormitory (Upstairs & Downstairs) and kitchen
- Electrical loads: Lights, sockets, heating system and kettles.

Electric Pump- 3Ø powered by all three phases.

System Measurements for Cabling:

- Distance from Array to controller = 20m
- Distance from system instalment to Tanesco main 8m, for three inverters inputs and outputs 8m x 6 = 48m

Array placement on the roof:

- Roof length = 8.5m
- Roof width = 9.7m

With all this information we were able to start the design of different options of solar power systems, varying the solar fraction, that is to say the amount of energy wanted to be covered by the irradiation of the sun:

Option 1: System covering 100% of the Load Analysis:

This option will be able to cover your energy consumption defined by the Load Analysis in an average day during the worst month of the year. It means it would be oversized for the rest of the year.

Cost Outline:	
Solar Modules (5565Watts)	$5,565.0
Charge Controller TS-MPPT-60 Morningstar x 2	$1,640.0
Battery bank 600Ah 48V	$4,800.0
Inverter Victron Energy I/C 3000VA 48V Multi	$6,150.0
Balance of System Estimate	$5,263.7
Installation	$1,557.6
Transport	$272.6
TOTAL CLIENT ESTIMATE	$25,248.9

Table. 6 Quotation for Option 1.

This system would include the following components:

- 21x 265W Suntech Solar Modules
- 2 x TS-MPPT-60 MorningStar Charge Controllers
- 12 x 200Ah AGM Surette Batteries
- 3 x Victron Energy Inverter Charger 3000VA
- Balance of system
- Installation and Transport

Option 2: System covering 75% of the Load Analysis with 18 hours of battery autonomy:

In this case the system will be able to cover 75% of the total defined consumption and the battery bank will have one day of autonomy covering 75%. That is to say around 18 equivalent hours of autonomy (instead of 24h). This is just an estimation, since the discharge of the batteries depends on when the loads in the load analysis are actually in use.

Cost Outline:	
Solar Modules (3975Watts)	$3,975.0
Charge Controller TS-MPPT-60 Morningstar x 2	$1,640.0
Battery bank 400Ah 48V	$3,200.0
Inverter Victron Energy I/C 3000VA 48V Multi	$6,150.0
Balance of System Estimate	$4,597.0
Installation	$1,557.6
Transport	$272.6
TOTAL CLIENT ESTIMATE	**$21,392.2**

Table. 7 Quotation for Option 2.

This system would include the following components:

- 15x 265W Suntech Solar Modules
- 2 x TS-MPPT-60 MorningStar Charge Controllers
- 8 x 200Ah AGM Surette Batteries
- 3 x Victron Energy Inverter Charger 3000VA
- Balance of system
- Installation and Transport

Option 3: System covering 50% of the load analysis with 12 hours of battery autonomy:

This applies the same approach as with option 2 but with 50% of the total defined consumption covered, instead of 75%. The battery bank will give you around 12h of autonomy, depending on when loads are in use.

Cost Outline:	
Solar Modules (3180Watts)	$3,180.0
Charge Controller VE Blue Solar MMPT 150/70 x	$820.0
Battery bank 400Ah 48V	$3,200.0
Inverter Victron Energy I/C 3000VA 48V Multi	$6,150.0
Balance of System Estimate	$4,764.6
Installation	$1,274.4
Transport	$272.6
TOTAL CLIENT ESTIMATE	**$19,661.5**

Table. 8 Quotation for Option 3..

This system would include the following components:

- 12x 265W Suntech Solar Modules
- 1 x150/70 Blue Solar MPPT Charge Controller
- 8 x 200Ah AGM Surette Batteries
- 3 x Victron Energy Inverter Charger 3000VA
- Balance of system
- Installation and Transport

Option 4 and 5 below are based on 50% of the load analysis,

Option 4 is almost identical to option 3, but with a smaller battery bank. Essentially this system will allow coverage of short Tanesco outages in poor sun months and at night. Longer outages would require the generator to be started to support the system.

Option 4: 50% Load Analysis below 1 day of autonomy

Cost Outline:	
Solar Modules (3180Watts)	$3,180.0
Charge Controller VE Blue Solar MMPT 150/70 -	$820.0
Battery bank 200Ah 48V	$1,600.0
Inverter Victron Energy I/C 3000VA 48V Multi	$6,150.0
Balance of System Estimate	$4,454.1
Installation	$1,557.6
Transport	$272.6
TOTAL CLIENT ESTIMATE	**$18,034.3**

Table. 9 Quotation for Option 4.

This system would include the following components:

- 12x 265W Suntech Solar Modules
- 1 x 75/15 Blue Solar MPPT Charge Controller
- 4 x 200Ah AGM Surette Batteries
- 3 x Victron Energy Inverter Charger 3000VA
- Balance of system
- Installation and Transport

Option 5: 50% Load Analysis but using one single inverter:
In this option we will be using one inverter instead of three. This will decrease costs, however we need to check if this system will be applicable to your convent by sending a technician. The use of one inverter will means that when power is drawn from Tanesco to support the system and charge the batteries then all the convent power will be drawn from one phase. Tanesco may not permit this approach. In addition you generator is also a three phase generator and will not have sufficient power to supply these power requirements on one phase.

Cost Outline:	
Solar Modules (3180Watts)	$3,180.0
Charge Controller VE Blue Solar MMPT 75/15 x	$120.0
Battery bank 400Ah 48V	$3,200.0
Inverter Victron Energy Quattro 10000VA 48V	$5,615.0
Balance of System Estimate	$2,905.9
Installation	$1,557.6
Transport	$272.6
TOTAL CLIENT ESTIMATE	**$16,851.1**

Table. 10 Quotation for Option 5.

This system would include the following components:

- 12x 265W Suntech Solar Modules
- 1 x 75/15 Blue Solar MPPT Charge Controller
- 8 x 200Ah AGM Surette Batteries
- 1 x Victron Energy Inverter Charger 10000VA
- Balance of system
- Installation and Transport

In these options we are mainly looking at reducing the battery capacity as it is the batteries that are the most expensive component of a solar power system. Since the main objective is to cut down the Tanesco energy bill then we have assigned batteries in order that night time loads do not require the use of Tanesco or the generator. However, if budget is a constraint then most effective way to reduce cost is to reduce the number of batteries. However, in poor sun months the batteries would then have insufficient capacity to maintain power independent of Tanesco or the generator.

Nomad Safaris Solar Power System

Nomad Safaris is a tour operator in Tanzania devoted to provide tourists with safaris mainly in Serengeti National Park, Ngorongoro Conservational Area and Tarangire and Manyara National Park. As some tour operator, Nomad Safaris possess a network of campsites distributed throughout these national parks.

These campsites are located in remoted areas were the grid is way too far so they cannot be connected to the grid. Tourists nowadays are becoming more demanding and the campsites need to have all the accommodation to be able to satisfy luxury tourism. Lighting, hot water, sockets and Wi-Fi are nowadays some of the need for every tourist during their safaris. In order to provide the clients with these services a source of power is needed and becomes a problem due to the remote location of these campsites.

Most of these campsites have started using a generator to run all the appliances of the campsites, but most of them have realized that this is becoming really expensive as well as noisy, especially for these areas where clients are looking for the relax and quietness that only the African Savana can provide.

Solar Power Systems provide a clean, renewable and quite source of energy that becomes ideal for these kind of facilities.

Since to perform a load analysis in the campsite became difficult both to perform but also to correctly estimate it, some data loggers where installed in the different lines of the generator to log the consumption during different months to be able to properly design a solar power system able to cover all the energy demand, so that the use of the generator would be stopped.

The data was presented in 3 different phases of the generator and being irregular in the data logging. That is to say, the data loggers where recording the instant power at different moments, however there was no regularity and the period between is record was irregular, hindering a lot the data analysis.

timestamp					curr_property
17/07/2017 10:03	17/07/2017	10:03:40	3	1	450
17/07/2017 10:04	17/07/2017	10:04:52	4	1	483
17/07/2017 10:05	17/07/2017	10:05:40	5	1	483
17/07/2017 10:06	17/07/2017	10:06:40	6	1	466
17/07/2017 10:07	17/07/2017	10:07:52	7	1	483
17/07/2017 10:08	17/07/2017	10:08:52	8	1	805
17/07/2017 10:09	17/07/2017	10:09:52	9	1	724
17/07/2017 10:10	17/07/2017	10:10:52	10	8	450
17/07/2017 10:18	17/07/2017	10:18:40	18	1	418
17/07/2017 10:19	17/07/2017	10:19:52	19	1	450
17/07/2017 10:20	17/07/2017	10:20:40	20	2	434
17/07/2017 10:22	17/07/2017	10:22:52	22	1	434
17/07/2017 10:23	17/07/2017	10:23:52	23	1	450
17/07/2017 10:24	17/07/2017	10:24:52	24	1	418
17/07/2017 10:25	17/07/2017	10:25:52	25	1	434
17/07/2017 10:26	17/07/2017	10:26:40	26	1	450
17/07/2017 10:27	17/07/2017	10:27:52	27	1	450
17/07/2017 10:28	17/07/2017	10:28:52	28	1	450
17/07/2017 10:29	17/07/2017	10:29:40	29	1	450
17/07/2017 10:30	17/07/2017	10:30:40	30	1	434
17/07/2017 10:31	17/07/2017	10:31:41	31	1	434
17/07/2017 10:32	17/07/2017	10:32:41	32	1	450

Table. 11. Extract of the data recorded by the data loggers in Nomad campsite. (7)

Example of the data recorded by the data loggers.

After analyzing the data a report was made with all the information needed to start a solar power system sizing design:

Example of Phase 1:

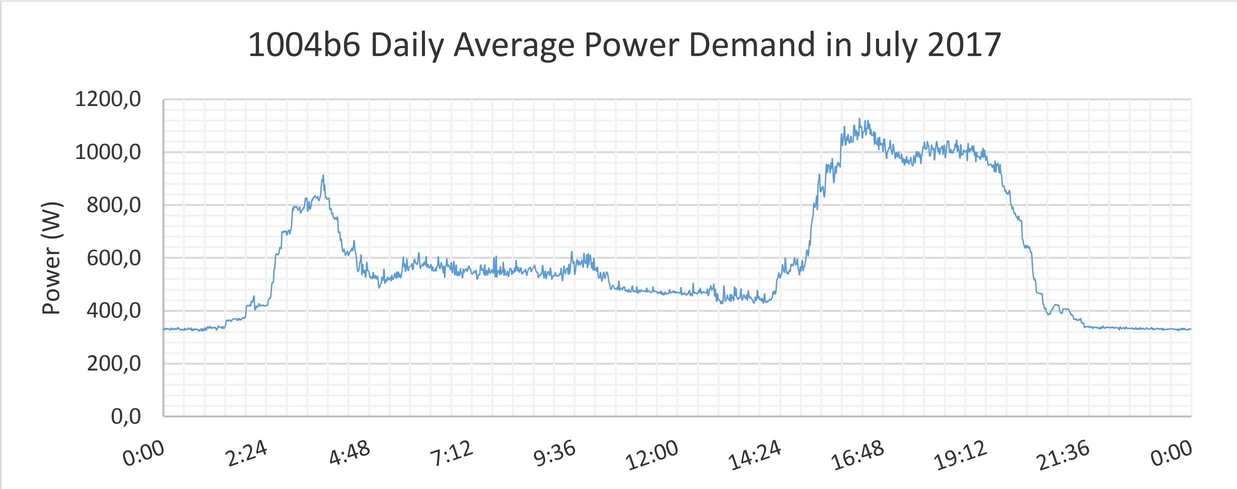

Figure. 19 Daily Average Power Demand in July 2017 of Phase 1 in Nomad campsite.

	Power (W)
Maximum	2680
Minimum	0
Average	590.8

Table. 13. Maximum, minimum and average power consumption.

	Energy (kWh)
Average Consumption per day	14.18

Table. 12.1 Average Consumption per day.

ENERGY:

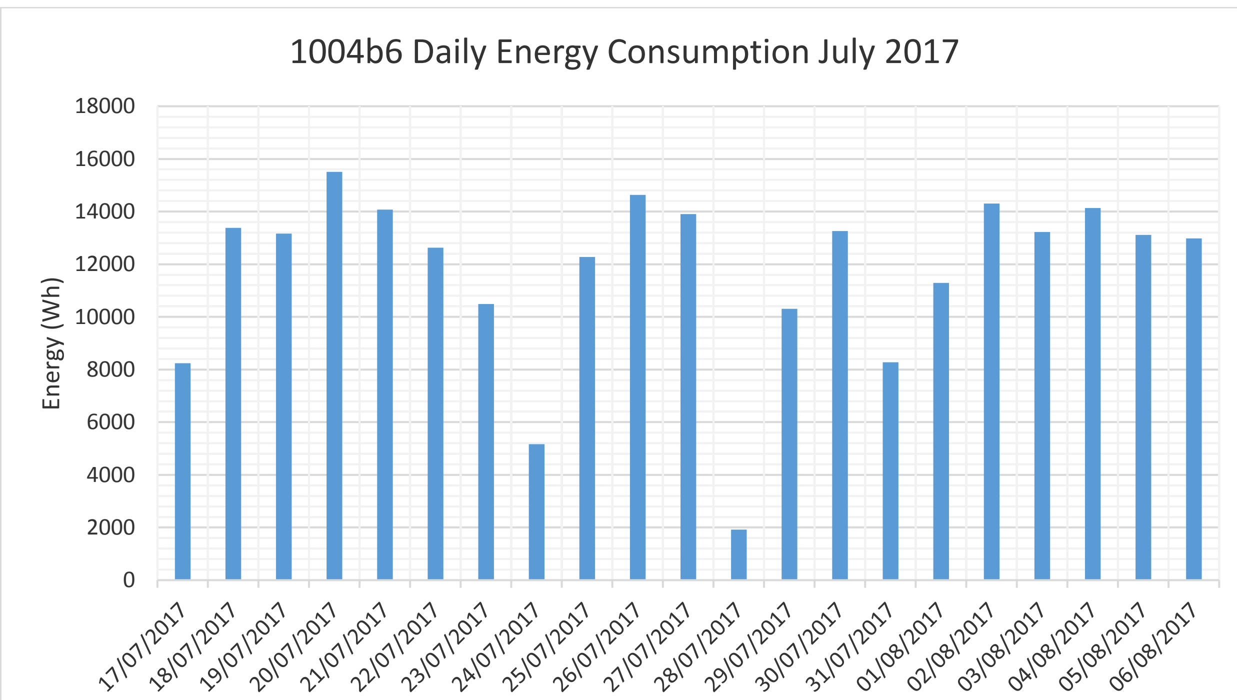

Figure. 20 Daily Energy Consumption in July 2017 of phase 1 of Nomad campsite.

MAX	15504 Wh

Hourly Energy Consumption

Time	Energy (Wh)
12:00 AM	329.90
1:00 AM	356.18
2:00 AM	527.89
3:00 AM	809.08
4:00 AM	603.59
5:00 AM	545.08
6:00 AM	562.69
7:00 AM	550.63
8:00 AM	549.14
9:00 AM	563.26
10:00 AM	508.39
11:00 AM	471.58
12:00 PM	468.65
1:00 PM	449.96
2:00 PM	523.64
3:00 PM	883.49
4:00 PM	1055.88
5:00 PM	989.80
6:00 PM	1008.18
7:00 PM	899.34
8:00 PM	499.49
9:00 PM	359.22
10:00 PM	334.00
11:00 PM	330.48
11:59 AM	329.90
Energy Consumption	14179.55

Table. 14 Hourly Energy Consumption during July 2017

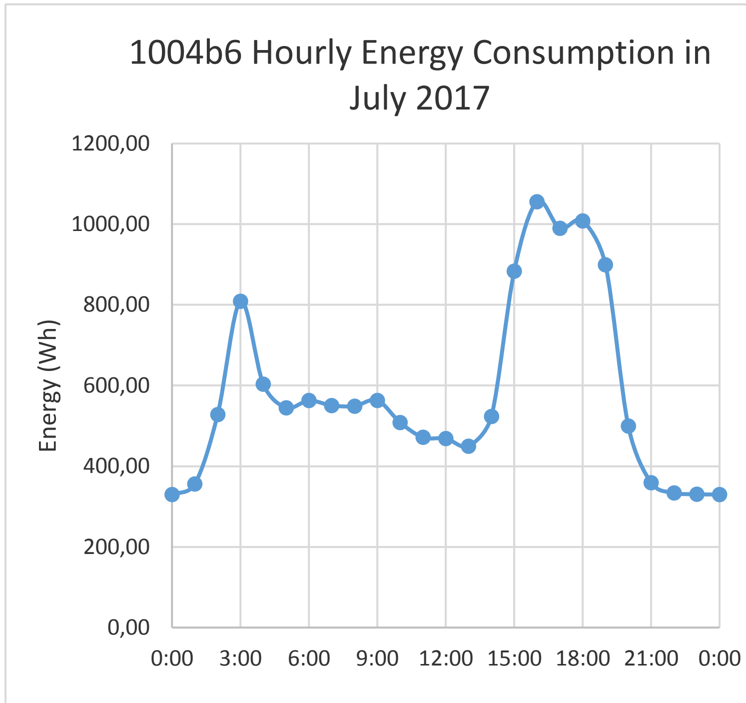

Figure. 21 Hourly Energy Consumption during July 2017

After analyzing all the phases one by one, the combined calculations results as follows:

Phase 1		Phase 2		Phase 3		COMBINED	
Time	Energy (Wh)	Time	Energy (Wh)	Time	Energy (Wh)	Time	Wh
12:00 AM	329,90	12:00 AM	0,00	12:00 AM	0,00	12:00 AM	329,90
1:00 AM	356,18	1:00 AM	0,00	1:00 AM	0,00	1:00 AM	356,18
2:00 AM	527,89	2:00 AM	0,00	2:00 AM	0,00	2:00 AM	527,89
3:00 AM	809,08	3:00 AM	0,00	3:00 AM	0,00	3:00 AM	809,08
4:00 AM	603,59	4:00 AM	0,00	4:00 AM	0,00	4:00 AM	603,59
5:00 AM	545,08	5:00 AM	2514,33	5:00 AM	2175,24	5:00 AM	5234,65
6:00 AM	562,69	6:00 AM	3205,32	6:00 AM	2746,31	6:00 AM	6514,32
7:00 AM	550,63	7:00 AM	2699,01	7:00 AM	3163,52	7:00 AM	6413,16
8:00 AM	549,14	8:00 AM	2982,53	8:00 AM	2590,21	8:00 AM	6121,88
9:00 AM	563,26	9:00 AM	3059,60	9:00 AM	3449,00	9:00 AM	7071,85
10:00 AM	508,39	10:00 AM	1024,83	10:00 AM	820,72	10:00 AM	2353,94
11:00 AM	471,58	11:00 AM	581,12	11:00 AM	214,37	11:00 AM	1267,06
12:00 PM	468,65	12:00 PM	554,07	12:00 PM	14,53	12:00 PM	1037,25
1:00 PM	449,96	1:00 PM	989,13	1:00 PM	465,04	1:00 PM	1904,14
2:00 PM	523,64	2:00 PM	1363,42	2:00 PM	1234,78	2:00 PM	3121,84
3:00 PM	883,49	3:00 PM	3563,32	3:00 PM	2180,00	3:00 PM	6626,82
4:00 PM	1055,88	4:00 PM	4402,42	4:00 PM	2934,23	4:00 PM	8392,52
5:00 PM	989,80	5:00 PM	3669,10	5:00 PM	2965,78	5:00 PM	7624,69
6:00 PM	1008,18	6:00 PM	3882,92	6:00 PM	2670,09	6:00 PM	7561,19
7:00 PM	899,34	7:00 PM	1853,13	7:00 PM	882,34	7:00 PM	3634,81
8:00 PM	499,49	8:00 PM	0,00	8:00 PM	0,00	8:00 PM	499,49
9:00 PM	359,22	9:00 PM	0,00	9:00 PM	0,00	9:00 PM	359,22
10:00 PM	334,00	10:00 PM	0,00	10:00 PM	0,00	10:00 PM	334,00
11:00 PM	330,48	11:00 PM	0,00	11:00 PM	0,00	11:00 PM	330,48
11:59 AM	329,90	11:59 AM	0,00	11:59 AM	0,00	11:59 AM	329,90
Energy Consumption (Wh/day)	12232,26		32652,81035		23633,84229		68518,91

Table. 15 Hourly Consumptions of the 3 phases and combined.

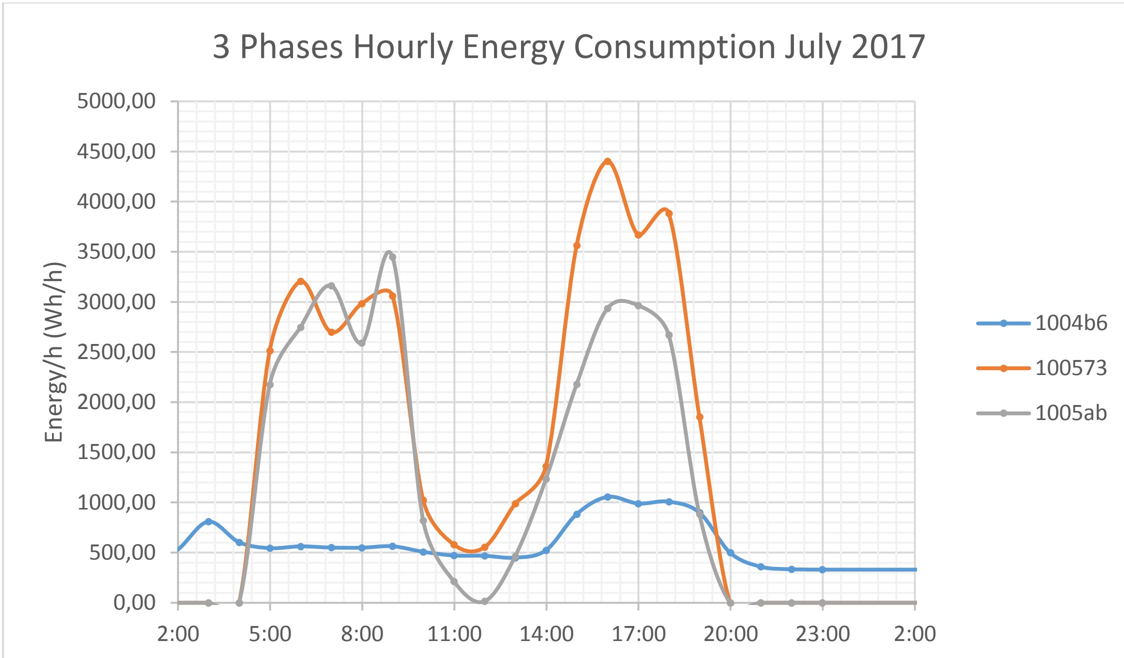

Figure. 22 3 Phases Hourly Energy Consumption in July 2017

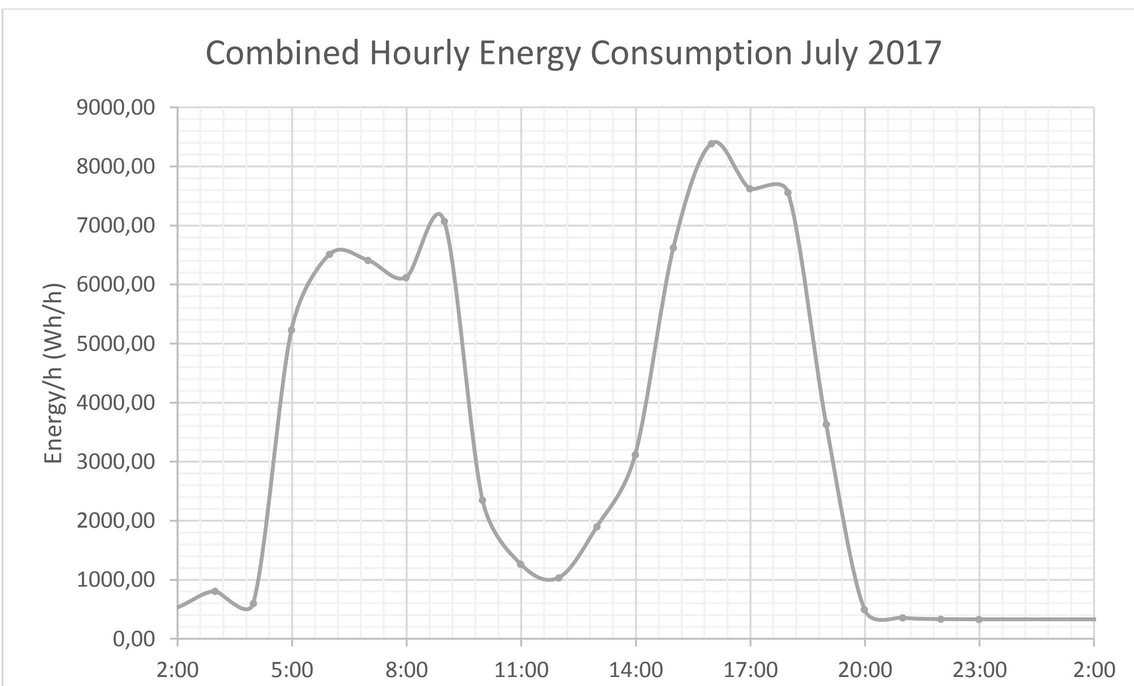

Figure. 23 Combined Hourly Energy Consumption in July 2017

With all these information the solar power system was designed following the usual method.

B. Back-Up Systems

Air Coastal Back-Up System:

Air Coastal is a local airline that provides local flights within Tanzania. Their offices is located in Arusha airport, around 4km far from Arusha. They had grid connection but they were suffering continuous power outages that were preventing the company to work properly and without interruption.

In order to solve this problem, a back-up system was suggested, so they could have a continuous source of power during the power cuts. Since these power outages were always shorter than 1 day, we designed this system to have only 1 day of autonomy. That is to say, the system could run continuously during a power outage, during one day, if the loads were equal as the ones estimated in the load analisys.

To size the battery bank a load analysis was needed and performed in their offices obtaining the information as follows:

Electrical Loads	Qty	Run Watts	Total Watts	Hours /Day	Ave. WH /Day	Percent of Total
Main office						
Lights energy sever	5	14	70	8,00	560,0	12,7%
Lights flourescent	4	40	160	8,00	1280,0	29,0%
laptop dell 6psc	3	65	195	8,00	1560,0	35,4%
TV BenQ (30inch)	1	70	70	8,00	560,0	12,7%
Charging phones	6	5	30	4,00	120,0	2,7%
Printer HP 220VAC 2A	1	480	480	0,20	96,0	2,2%
TRA Machines 9.6VDC 0.51A	2	5	10	3,00	30,0	0,7%
Router 29.5VDC 0.46A	1	22	22	8,00	176,0	4,0%
Fridge (Tanesco segregated)	0	90	0	0,00	0,0	0,0%
Store room						
Light flourescent	1	40	40	0,50	20,0	0,5%
Toilet light	1	14	14	0,50	7,0	0,2%
		Total Daily Average Watt-hrs				4409,0
		Largest AC Appliance Wattage				480
		Total AC Wattage (Inverter Power Demand)				1091

Table. 16 Load Analysis of the offices of Air Coastal. (8)

Once the consumption is known as well as the inverter power demand we can proceed to design the backup system and to prepare a quotation:

Cost Outline:	
4 x Surrette/Rolls S-220 12V AGM Battery	$1.600
Inverter Victron Energy I/C 1600VA 24V Multi	$1.225
Balance of System Estimate	Not Included
Installation	$566
Transport	$130
TOTAL CLIENT ESTIMATE	**$3.521**

Table. 17 Cost outline for Air Coastal Solar Power System. (8)

The backup system designed was formed by 4 batteries, distributed 2 in parallel and 2 in series to provide 24V (400Ah at that voltage) and a Victron Energy Inverter of 1600VA and 24V, able to meet tha maximum load estimated.

C. Technical Support

Hoopoe Safaris - Tarangire Lodge Systems Solar Power Systems

This camp is powered by 3 Solar Systems:

1. **Kitchen refrigeration system.**

This system is supposed to supply energy to one refrigerator and one freezer, whose power consumption specifications are as follows:

- DCF225 Freezer.
  Average Energy Use: **532 Wh/day** at 32°C // 44 Ah/day at 12V, 32°C
- DCR165 Refrigerator.
  Average Energy Use: **168 Wh/day** at 32°C // 14 Ah/day at 12V, 32°C

The stand-alone system is consisting of:

- 4 Solar modules of different brands (in good state) (320W):
  a. 1 BPSOLAR 80W 12V Polycrystalline.
  b. 3 Solarex Modules Unknown Specifications. Same size than the other one. Probably 12V since they were connected in parallel.
- 1 Morning Prostar-30 12V PWM in good condition.
- 3 Aeka Batteries 12V 186Ah in parallel. (9)

Figure. 24 Kitchen Refrigeration System of Tarangire Lodge.

<u>Overall Assessment</u>:

The condition of the batteries make the system almost useless. Battery replacement would be needed to run both refrigeration devices. Modules and charge controller seem they can be still used (verify the Solarex modules are actually 12V would be necessary).

2. **Bar refrigeration system.**

This system is supplying:

- DCF225 Freezer.
  Average Energy Use: 532 Wh/day at 32°C // 44 Ah/day at 12V, 32°C
- DCR165 Refrigerator.
  Average Energy Use: 168 Wh/day at 32°C // 14 Ah/day at 12V, 32°C

The stand-alone is consisting of:

- 9 Suntech 120W 12V Polycrystalline modules in parallel (1080W).
- 2 Morning Star Ts-45 PWM
- 6 Batteries S-530 6V 400Ah apparently in good condition, some of them with not enough water.
- 1 Tripp-lite 750W APS X Series 12VDC 230V Inverter/Charger.

Figure. 25 Bar Refrigeration System of Tarangire Lodge.

Overall Assessment:

This system works properly, but some batteries need to get better maintenance, since 3 cells were without enough water. System probably oversized for only two low-power refrigeration devices. Generator connected to the inverter charger to charge batteries if necessary.

3. Main System

The loads gathered in the load analysis are covered by the main system assisted by the diesel generator:

Kubota Diesel Generator

GV – 1160 – 50 –B

15Kva – 15kW

240V – Hz

62.5 A – 1500rpm

1phase – 4 poles

Figure. 26 Kubota Diesel Generator.

The main system is constituted by:

- 8 Modules KC125GT 125W 12V Polycrystalline (1000W)
- 2 Morning Star Ts-45 PWM
- 8 Batteries S-530 6V 400Ah
- Victron Multiplus 2000VA 12V 80ADC

Figure. 27 Main Solar Power Sytem of Tarangire Lodge.

Overall Assessment:

Figure. 28 Batteries of the Main Solar Power System of Tarangire Lodge.

12V system connected to the generator. The batteries are not working properly, since the generator is working longer than some time ago. The rest of the system seems to be in good condition.

- 72 Pathway lights (8 and 11W) are connected to the generator, thus they are always on while the generator is running. They are supposed to be incorporated to the main system and to be on from 18h to 22h approximately.

The main objective is to use the generator as less as possible. High consumption lights will need to be replaced. Batteries of the systems 1 and 3 will need to be replaced. Modules of system 2 and 3 can be reorganized more accurately. Probably new modules need to be added to the main system depending on the amount of energy to be covered by solar.

6. Conclusion

An internship gives a master student not only a really important extra education but also one of his first working experiences in a real company and the first contact with the “real world”. The main objective for an intern is to gather as much experience as possible and to learn as much as possible to become a real professional in the future.

However, an internship in Africa can offer a lot more. As pointed out during the whole document, Tanzania is considered a developing country, where the resources and means are very limited, not only for living but also for working.

An internship in Tanzania teaches you how to work with limited resources, how to react to unexpected things, how to deal with people from a completely different culture and how to use your work to actually help people.

Although when students become interns in a company they already have a good base of technical knowledge, this knowledge is normally focused and taking for granted that the work will be done in a western country. However, in Africa, things become different than Europe, the US, oy any developed country. When a problem comes or a job needs to be done, companies normally have a methodical way of acting, however, this doesn’t work in Tanzania. This country teaches you a skill to think creative solutions for unforeseen circumstances or conditions, or new situations that you haven’t experienced before.

An internship is a powerful tool a university can offer a student during his studies that will definitely help him in his professional career. However, an internship in Africa gives you not only that, but also a lifetime experience.

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